Measurement of Contrast Ratios for 3D Display

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ABSTRACT

3D image display devices have wide applications in medical and entertainment areas. Binocular (stereoscopic) imaging without glasses, especially spatial-multiplexed displays such as lenticular display, barrier strip display, and single-lens stereoscopic display, is one of the most powerful and popular ways for life-like presentation of our three-dimensional environments.

The definition and relationship of the image contrast and viewer crosstalk are reviewed and clarified. They are measured and compared on three different types of 3D display systems, including shutter-glasses stereoscopic display, image splitter autostereoscopic display and dual-panel autostereoscopic display.

From the contrast point of view, high-quality three-dimensional perception results from a combination of high image contrast and low crosstalk. Same as a conventional two-dimensional display, high image contrast is also required for a 3D display to present a satisfactory image to either eye of the viewer. Yet, there is an extra requirement for a 3D display. The viewer crosstalk must be low enough for the viewer's one eye to neglect the ghost image from the neighboring viewing zone of the other eye.

The interesting fact is that there are conflicts between these two factors to generate satisfactory 3D effects. As a characteristic of the display system, the system crosstalk will confine a content provider within a certain range of image contrast to present satisfactory 3D pictures or videos to the viewer.

1. INTRODUCTION

The elementary cues of 3D vision from a stereoscopic display system are from a serious of images with lateral disparity. When two of the images with proper disparity are fed into a viewer's two eyes, the viewer obtains his first cue of 3D perception - binocular vision. The viewer will obtain his second cue from the display while he moves his head laterally and sees different images from the corresponding aspect. This is called the motion parallax. Therefore, an ideal stereoscopic display has to make efforts to present corresponding images at different viewing angles to let the viewer obtain binocular parallax and motion parallax.

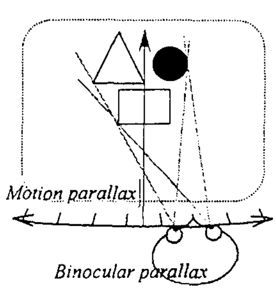

Figure 1. Stereopsis – a combination of the binocular parallax and motion parallax.

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Some of the earlier researches in the physiological optic area pointed out that the quality of the 3D perception depends on the contrast of the composing 2D images[1, 2, 3]. The higher the image contrast is, the better the 3D perception will be. But probably they did not have a more practical display system as today, usually they obtained their conclusion about how monocular contrast affects stereo acuity by using "mirror stereoscopic" experimental setups.

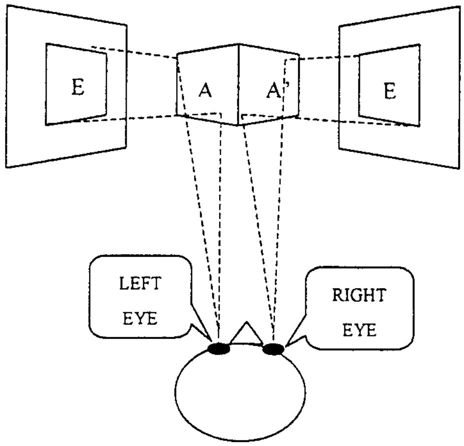


Figure 2. Mirror stereoscopic display. From the reflection of the two mirrors (A and A'), the two pictures are presented into the two eyes of the viewer, without any "crosstalk" problem.

In the recent years, a new important factor, which is called "ghost image", arises during the development of the stereoscopic display technologies. The "ghost image" results from the crosstalk between the viewing zones for the left and right eyes of the viewer. The amount of the crosstalk reduces the ability of the viewer to fuse the two eye views into a single, 3 dimensional one.

Therefore, we would like to clarify the difference between the image contrast (this affects the monocular image quality) and viewer crosstalk in this paper. Furthermore, the relationship between the image contrast, system crosstalk and viewer crosstalk will be discussed.

2. BACKGROUND OF 3D DISPLAY

Let's take an overview of 3D display technology[8 9]. There are various ways of creating a three dimensional display. The practical methods that meet the necessary attributes fall into three categories: Hologram displays, spatially multiplexed displays and time multiplexed displays.

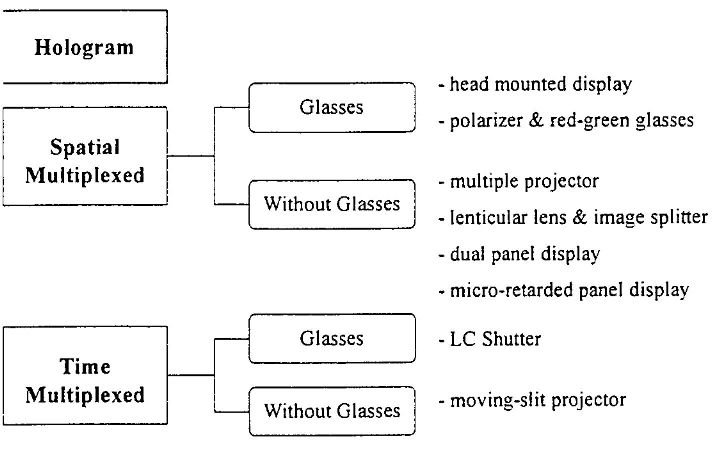


Figure 3. Three categories of 3D display.

In this paper, we will evaluate the interaction between the image contrast and viewer crosstalk by experiments on four different stereoscopic display systems, representing different categories of stereoscopic display respectively. The four display systems are described as following.

2.1 SHUTTER-GLASSES STEREOSCOPIC DISPLAY

A widely applied display method using time multiplexed method to present binocular visions[4].

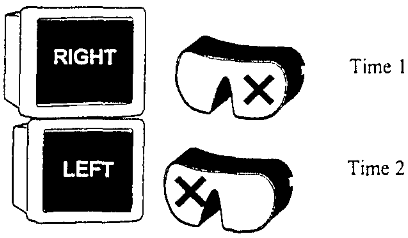


Figure 4. Shutter Glasses: Time 1 to show one eye's image, and Time 2 to show the other.

2.2 IMAGE SPLITTER AUTOSTEREOSCOPIC DISPLAY

An image splitter autostereoscopic display, or parallax barrier autostereoscopic display, is made by placing a barrier-strip plate in front of an image display panel at a pre-designed distance. Each image to be presented on such a display is vertically interlaced from two images of different parallax, one for the right eye and the other for the left eye.

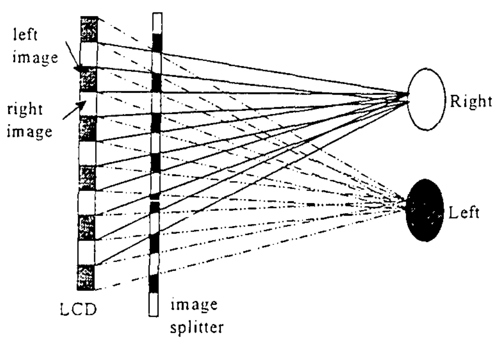


Figure 5. Image splitter autostereoscopic display.

2.3 DUAL-PANEL AUTOSTEREOSCOPIC DISPLAY

Mahler[6] used two pieces of transparencies in front of large lenses and a beam splitter to combine the two images, and now we use LCD panels to replace the light sources and transparencies.

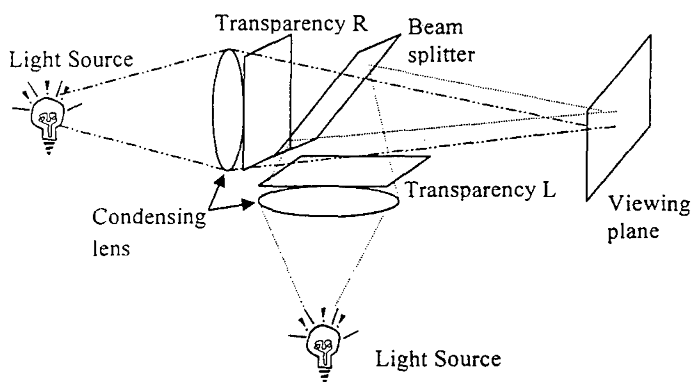


Figure 6. A dual-panel autostereoscopic display adapted from Mahler's "Photoplastikon".

3. THE DEFINITIONS

Before we give a more precise definition to the various contrasts and crosstalks[5 6], we will introduce "co-location point" first.

While watching a 3D object in the real world, there will be two different 2D images (with disparity) formed on the retinas of the two eyes of the viewer. There will be various discrepancies between these two images because they have disparity. Like in figure 7, at a specific location on the display screen one will find a part of one image (e.g., the right edge of a rod in the right-eye image), and an adjacent part of the other image (e.g., the background in the left-eye image). The representing position (x_0, y_0) of these two parts on the two images is defined as "co-location point" in this paper. Please be noted that, the definition of the "co-location point" is different from that of the "corresponding point", which is point A and A' in the right-eye image and left-eye image respectively.

It is not expected to see ghost images on an ideal stereoscopic display. However, most of people will notice and be bothered by ghost images on stereoscopic displays, especially on an autostereoscopic display. The ghost image is usually due to the incapability of the display system to totally clear up the light leakage from the co-location point of the other eye's image.

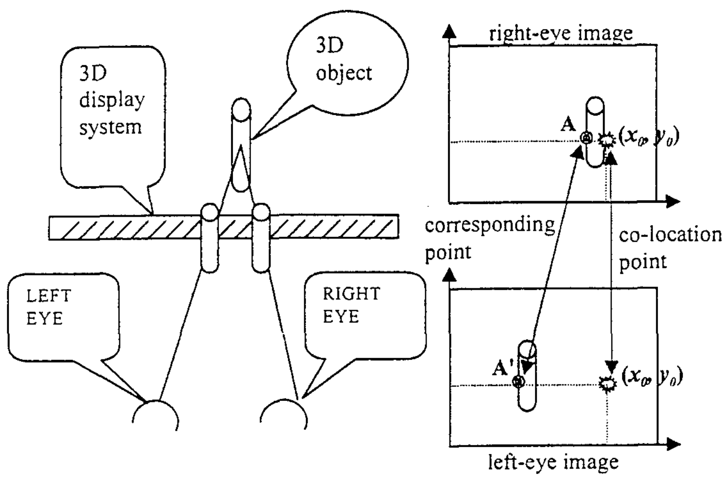
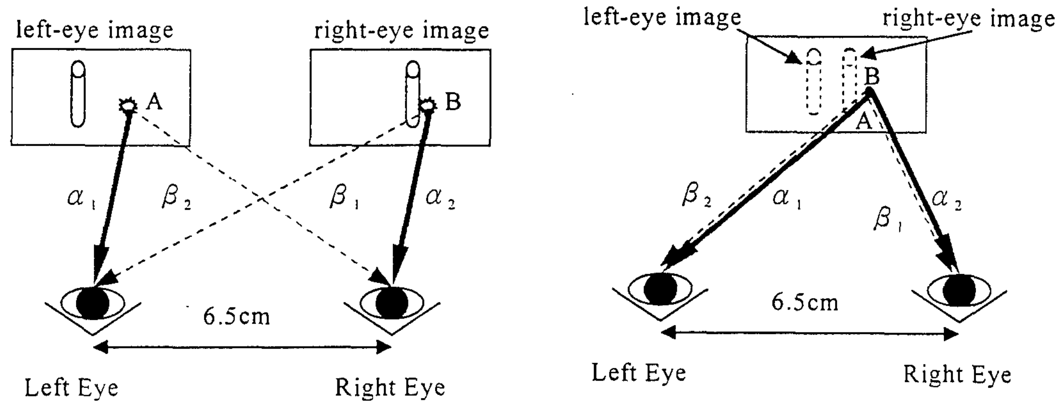


Figure 7. A diagram for explaining a stereoscopic display system to show a 3D object.

Now please refer to Figure 8. Numbers A and B are the luminance values at the specified points on the screen, and α_1, α_2, β_1, β_2 are stereoscopic display system parameters. In Fig. 8a, A and B represent the luminance value of the co-location points on left-eye and right-eye images, respectively, in a dual panel autostereoscopic display. In Fig. 8b, A and B represent the luminance value of the co-location points on interlaced left-eye and right-eye images, respectively, in the other three stereoscopic displays. α_1, α_2 describe the percentage part of the left-eye image should be observed at the left-eye position and the percentage part of the right-eye image should be observed at the right-eye position, respectively. β_1 and β_2 describe the percentage part of the left-eye image leaked to the left-eye position and the percentage part of the right-eye image leaked to the right-eye position, respectively.



(Fig.8a) **(Fig.8b)**

Figure 8. Diagram for the parameters for the definitions. Fig.8a is for dual panel system examples, Fig.8b is for single panel system examples.

3.1 CO-LOCATION IMAGE CONTRAST

When a 3D content is displayed on a stereoscopic display, the co-location image contrast of a specific point on the screen is "defined as" the luminance ratio of the co-location points of the two images (left-eye and right-eye) at that specific position. Carefully review the above definition, the co-location image contrast is actually affected by two different factors, the content itself and the image source property (e.g., the panel contrast of LCD or CRT).

For a left-eye case, the co-location image contrast can be defined as the luminance ratio **B/A**.

Note that the co-location image contrast is different from the well-known image contrast which is defined as the luminance ratio of the point with maximum luminance to the point with minimum luminance for the entire 2D image.

It is easy to prove that if the image contrast is adjusted to a new value, the relationship between the new co-location image contrast and the image contrast will follow the equation

$$v'/u' = (v + c)/(u + c) \qquad (1)$$

where v'/u' is the co-location image contrast before adjustment, v/u is the co-location image contrast after adjustment; c is a constant equal to $L_{min} \times (C_r - C_r')/(C_r' - 1)$, where C_r and C_r' are the image contrast before and after adjustment as defined above, L_{min} is the minimum luminance in the image before adjustment. Taking a detail look at the relationship, we can find out that the co-location image contrast for each specific co-location pair will increase when the 2D image contrast of each single-view image gets higher.

3.2 SYSTEM CROSSTALK

This value is used to evaluate the optical performance of the stereoscopic display system, and is independent of the content. From Figure 8, for a left-eye case, the system crosstalk can be defined as β_2/α_1, describing the degree of the unexpected leaking image from the other eye.

3.3 VIEWER CROSSTALK

In the former two paragraphs, the two important factors affecting the ghost image a stereoscopic viewer will sense are defined. Here the authors will further quantize the "ghost image", or the viewer crosstalk, which is measured at the viewer's side. The viewer crosstalk is defined as the ratio of the luminance of unwanted "ghost" image to the luminance of the correct information received by the viewer's eyes[6]. Referring to Figure 8, the viewer crosstalk for the viewer's left eye can be defined as $\mathbf{B}\beta_2/\mathbf{A}\alpha_1$.

4. MEASUREMENT OF SYSTEM CROSSTALK

From the above definitions, a simple relationship can be found. The viewer crosstalk $B\beta_2/A\alpha_1$ can be written as the product of **(B/A)** and (β_2/α_1), or

viewer crosstalk = co-location image contrast * system crosstalk ------------------------- (2)

For the simplicity of measurement, the viewer crosstalk can be expressed as $(B\alpha_2/A\alpha_1) * (\beta_2/\alpha_2)$, too. We measured the different stereoscopic systems in our laboratory and verified the above relationships.

For the purpose of quantification, different levels of gray-scaled patterns are applied for measurement. For every display system, the quantities $B\beta_2/A\alpha_1$ and $B\alpha_2/A\alpha_1$ are measured with different gray scales of patterns. All the measurements are done by Minolta CS-100 luminance meter.

4.1 SHUTTER-GLASSES STEREOSCOPIC DISPLAY

This experimental system is specified as the following. The display device is a CRT display with P 22 phosphors, SVGA resolution, and refresh rate 120 Hz. The shutter-glasses is purchased from APEC Inc., Taiwan, model number VR97. The shutter-glasses is fixed in front of the CRT (with a distance of 60 cm and the luminance meter is positioned behind the glasses. The result is,

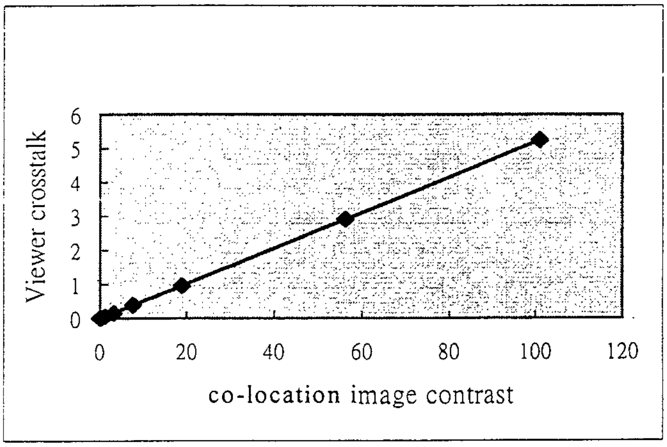


Figure 9. Viewer crosstalk of shutter glasses stereoscopic display.

4.2 IMAGE SPLITTER AUTOSTEREOSCOPIC DISPLAY

The image splitter autostereoscopic display specifications are, the display device is Sanyo's 15" LCD with double image splitter, with luminance 400 cd/m^2, proper viewing distance 23", and XGA resolution. The luminance meter is set at the best observation position. The result is,

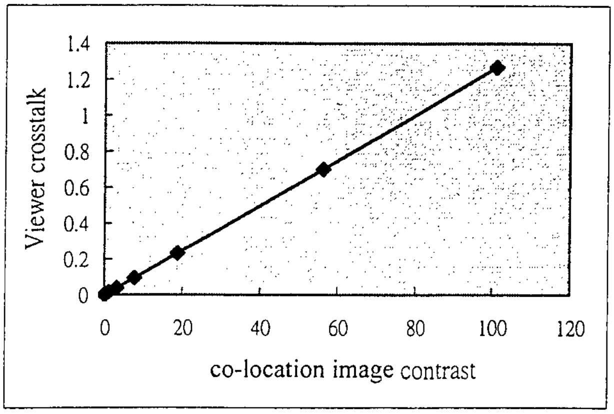


Figure 10. Viewer crosstalk of image splitter autostereoscopic display.

4.3 DUAL-PANEL AUTOSTEREOSCOPIC DISPLAY

This experimental system is a little bit more complicated, please refer to figure 6. The LCD panels are Philips' 15.1" XGA panels, screen luminance is 7 cd/m^2, and the most proper viewing distance is 60 cm. The backlight brightness and panel contrast are adjusted to the same level for the two LCDs. The result is,

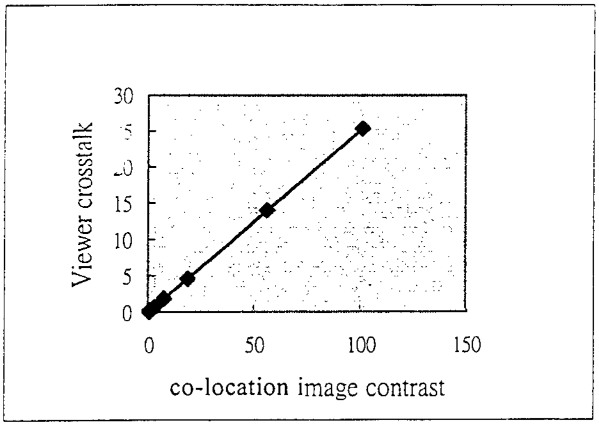


Figure 11. Viewer crosstalk of dual-panel autostereoscopic display.

5. DISCUSSION

Observing the above measurement results, it is obvious that the slopes β_2/α_2 in the plots are all basically constants for every case. Refer to equation 2, the parameter β_2/α_2 differs from the system crosstalk of the stereoscopic systems (β_2/α_1) by a constant α_2/α_1. For a practical system, it is reasonable to believe that α_1 and α_2 are close to each other. In such a case, the slopes will be close to the system crosstalk of the stereoscopic system and can also be used to characterize the stereoscopic system. The slopes β_2/α_2 for the different 3D systems can be summarized as following.

system	shutter-glasses	dual-panel	image splitter

Slope	0.058	0.28	0.014

The system crosstalk (or the slope β_2/α_2) is an index of optical performance for a stereoscopic system. The smaller the system crosstalk is, the less possible the viewer is tending to see ghost image. It is independent of the content, such as the co-location image contrast, single-view image contrast or the image brightness. In this paper, the system crosstalk is measured from the centers of the viewing zones (of our autostereoscopic displays to acquire a best result. Yet practically the viewer's eyes are not necessarily fell in the best position while watching autostereoscopic images. In fact, the system crosstalk will increase as the position of measurement leaves the center of the viewing zone. Therefore, the variation of the value of the system crosstalk ratio may indicate the range in which one can obtain 3D vision with good quality on a stereoscopic display.

However, the parameter that finally determines the level of ghost image the viewer will see is the viewer's crosstalk instead of the system crosstalk. It is clear that the co-location image contrast is defined for interpretation for the relationship of the system crosstalk and the viewer crosstalk. Therefore, it is a localized property of the image, i.e., the value of the co-location image contrast is decided from a co-location point of the left-eye and right-eye images.

For a 2D display, the higher the image contrast is, the better the visual quality will be. But this is not necessarily correct for a stereoscopic display. According to equation 2, the viewer's crosstalk is proportional to the co-location contrast. That means as the co-location contrast gets higher and higher, the ghost image phenomena will become worse and worse. It has been mentioned in the previous paragraph that the co-location contrast and the single-view image contrast has a positive relationship, i.e. increase in one value will also induce increase in the other, and vice versa. Under this fact, although the image contrast is indeed proportional to the visual quality for monocular vision of the viewer, a higher image contrast will on the contrary cause more crosstalk for a stereoscopic system. It is because the better image contrast will be easier to induce "ghost image" due to the non-infinitesimal value of the system crosstalk. In another word, the image contrast could be a conflict factor with the system crosstalk in a stereoscopic display system. The "viewer crosstalk" is then an overall evaluation for the ghost image, and is easy to be interpreted due to the principle of binocular 3D display[4].

6. CONCLUSION

In this paper, a simple method to measure the system crosstalk is pointed out and a relationship between the image contrast and viewer crosstalk is established[10] . Our result can get the following conclusions:

1.When the system crosstalk is a constant, the image contrast is not the higher the better. This result does not depend on any specific system. At least, from the four different stereoscopic displays the same conclusion is derived.

2. System crosstalk is a evaluation of the performance of a stereoscopic display. Stereo contrast is equal to the product of the image contrast and system crosstalk.

In many 3D display systems viewer' crosstalk is an important issue for good performance, especial in autostereoscopic display systems. For an autostereoscopic display system, system crosstalk is not always the same when observer is at different position in front of the screen, even there is a tracking system. Therefore, the viewing angle of the system can be decided by the system crosstalk measurement at different positions. On the other hand, the viewer crosstalk describing the seriousness of ghost image is an overall result of the image contrast and the system crosstalk. Image processing method can be applied to decrease image contrast to decrease viewer crosstalk.

There are still issues should be studied further. For example, the maximum viewer's crosstalk allowed for a viewer to obtain good 3D perception. This paper probes criteria for a good 3D display only from the luminance point of view, other factors like spatial frequency and cross- or uncross- disparity are not considered yet[7].

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REFERENCES

1. D Lynn Halpern ,Randolph R Blake, "How contrast affects stereoacuity ",*Percetion*,1988,volume 17,number 4,page 483-495

2.Blake R, Cormack R H,1979 "Does contrast disparityalone generate stereopsis?" *Vision Research* **19** 913-915

3.Friby J P, Maybew J E W, 1978 "Contrast sensitivity function for stereopsis " *Perception* 7 423-429

4 Y. Yeh and L.D. Silverstein, "Limits of fusion and depth judgement in stereoscopic color displays", *Human Factors*, v.32, pp. 45-60, 1990.

5. Peter G.J.Barten ".Contrast Sensitvity of the HUMAN EYE and Its Effect on Image " *SPIE OPTICAL ENGINEERING PRESS.*

6. S.A. Benton, T.E. Slowe, A.B. Kropp and S.L. Smith, "Micropolarizer-based multiple-viewer autostereoscopic display", *Proc. SPIE* 3639, *SPIE Symposium on Stereoscopic Displays and Applications X,* pp.76-83, Feb. 1999.

7 Y. Yeh and L.D. Silverstein, "Human Factor for stereoscopic color displays", SID 91 Digest, pp. 826-829.

8. .J.R. Moore, N.A. Dodgson, A.R.L. Travis and S.R. Lang, "Time-multiplexed color autostereoscopic display", *Proc. SPIE* 2653, *SPIE* Symposium on Stereoscopic Displays and Applications VII, pp. 10-19, Feb. 1996.

9. S.A. Benton, "The second generation of the MIT holographic video system," in: J. Tsujiuchi, J. Hamasaki, and M. Wada, eds., Proc. of the TAO (Telecommunications Advancement Organization of Japan) *First International Symposium on Three Dimensional Image Communication Technologies*, pp. S-3-1-1 to –6, Dec. 1993..

10.H. Morishama, H. Nose, N. Taniguchi ,K. Inoguchi, S. Matsumura "An Eyeglass-Free Rear-Cross-Lenticular 3-D Display" , *SID* DIGEST 98